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FUEL INJECTION ARRANGEMENT

The present invention relates to a fuel injection arrangement for a combustor of a gas turbine engine and in particular a prefilmer for the fuel injection arrangement.

There is an increasing demand to reduce the emissions produced by gas turbine combustors for aerospace, marine and industrial applications. One approach is to use lean fuel/air ratio combustion. A preferred lean direct injector is disclosed in US6,272,840. This injector comprises a pilot injector surrounded by a coaxial main injector. The pilot injector provides a pilot flame that has a relatively high, but stable fuel/air ratio. The main injector provides a main flame that has a lean fuel/air ratio. The main injector supplies the majority of the combustion gases above low power so that low levels of oxides of nitrogen (NOx) emissions are obtained because the main injector produces a uniformly mixed fuel-air mixture at an equivalence ratio less than stoichiometric. This mixture burns at a relatively low flame temperature avoiding the NOx producing high temperature volumes of more conventional combustion systems.

To assist mixing of fuel and air a prefilmer is mounted between radially adjacent swirl vanes. Fuel is shed from the downstream edge of the prefilmer, and is atomised as it passes through a shear region formed by the swirl vanes. In a typical lean burn fuel injector this is the only purpose of the prefilmer.

Although lean burn combustion systems can produce NOx emissions levels significantly lower than conventional combustion systems, there is a severe disadvantage, combustion instability. Where variations in heat release and pressure are in phase, the magnitude of both fluctuations will increase. The severity of the combustion instability produced varies from an irritating noise to a force powerful enough to stall gas turbine compressors and

shake combustion systems apart. In a conventional aerospace gas turbine combustion system, different areas within the combustor operate at different air-fuel ratios. Here, fluctuations in heat release become out of phase relative to each other resulting in a reduction of the net heat-release. In a lean burn system, as the system runs at a uniform air-fuel ratio, all parts of the combustion system tend to oscillate in phase with each other. Net heat release fluctuations therefore tend to be high.

Therefore an object of the present invention is to provide a means for reducing combustion instability and in particular reducing net heat release fluctuations within the combustor.

Accordingly the present invention seeks to provide a prefilmer for a fuel injection arrangement comprising a body having a fluid flow surface and a downstream edge, the prefilmer arranged so that when working in operative association with the fuel injection arrangement fuel flows over the surface, by means of a passing airflow, to the downstream edge, from where the fuel is shed, characterised in that the prefilmer further comprises a fluid flow mixing means to, in use, enhance the mixing of fuel and air.

Preferably, the fluid flow mixing means comprises projections extending generally downstream from the downstream edge; the projections are generally trapezoidal in shape. Alternatively, the projections are generally triangular in shape.

Preferably, the projections define trapezoidal notches therebetween, but alternatively the notches are triangular.

Preferably the projections are radially inwardly angled. Alternatively, the projections are radially outwardly angled and furthermore the projections are alternately radially inwardly and outwardly angled. It is preferred that the angle of the projections is between 0 and 45 degrees relative to an injector axis.

Alternatively, the fluid flow mixing means comprises the downstream edge configured in a generally sinusoidal form in its axial direction or alternatively in its radial direction.

Alternatively, the fluid flow mixing means comprises lands disposed to the downstream edge, the lands are configured to generate and impart, in use, vortices into the passing airflow to enhance the mixing of fuel and air. In a preferred embodiment, the lands comprise a leading edge, two opposing sides, a leeward face and a base attached to the fluid flow surface.

Alternatively, the fluid flow mixing means is asymmetrically arranged about the prefilmer.

Figure 1 is a schematic section of a ducted fan gas turbine engine incorporating an embodiment of the present invention.

Figure 2 is a sectioned schematic view of a first embodiment for a piloted airblast lean direct fuel injector incorporating a first embodiment of a fluid flow mixing means in accordance with the present invention.

Figure 2a is an illustrative enlarged perspective view of the fluid flow mixing means shown in Figure 2.

Figure 3 shows a second embodiment of the fluid flow mixing means in accordance with the present invention.

Figure 4 shows a third embodiment of the fluid flow mixing means in accordance with the present invention.

Figure 5 is a perspective view of a fourth embodiment of the fluid flow mixing means in accordance with the present invention.

With reference to figure 1, a ducted fan gas turbine engine 110 comprises, in axial flow series an air intake 112, a propulsive fan 114, a core engine 116 and an exhaust nozzle assembly 118 all disposed about a central engine axis 120. The core engine 116 comprises, in axial flow series, a series of compressors 122, a combustor 124, and a series of turbines 126. The direction of airflow through

the engine 110 in operation is shown by arrow A. Air is drawn in through the air intake 112 and is compressed and accelerated by the fan 114. The air from the fan 114 is split between a core engine flow and a bypass flow. The core engine flow passes through an annular array of stator vanes 128 and enters core engine 116, flows through the core engine compressors 122, where it is further compressed, and into the combustor 124 where it is mixed with fuel, which is supplied to, and burnt within the combustor 124.

Combustion of the fuel mixed with the compressed air from the compressors 122 generates a high energy and velocity gas stream that exits the combustor 124 and flows downstream through the turbines 126. As the high energy gas stream flows through the turbines 126 it rotates turbine rotors extracting energy from the gas stream which is used to drive the fan 114 and compressors 122 via engine shafts 130 which drivingly connect the turbine 126 rotors with the compressors 122 and fan 114. Having flowed through the turbines 126 the high energy gas stream from the combustor 122 still has a significant amount of energy and velocity and it is exhausted, as a core exhaust stream, through the engine exhaust nozzle assembly 118 to provide propulsive thrust. The remainder of the air from, and accelerated by, the fan 114 flows through an annular array of guide vanes 132 within a bypass duct 134 around the core engine 116. This bypass airflow, which has been accelerated by the fan 114, flows to the exhaust nozzle assembly 118 where it is exhausted, as a bypass exhaust stream to provide further, and in fact the majority of, the useful propulsive thrust. The combustor 124 incorporates a fuel injection arrangement (not shown), which is in accordance with the present invention.

Referring now to Figure 2, the fuel injection arrangement suitable for a gas turbine engine is generally indicated at 60. The fuel injection arrangement 60 is attached to the upstream end of a gas turbine engine

combustion chamber 11, part of which can be seen in Figure 2. Throughout this specification, the terms "upstream" and "downstream" are used with respect to the general direction of a flow of liquid and gaseous materials through the fuel injection arrangement 60 and the combustion chamber 11 as shown by arrow A. Thus with regard to the accompanying drawings, the upstream end is towards the left hand side of the drawing and the downstream end is towards the right hand side. The actual configuration of the combustion chamber 11 is conventional and will not, therefore, be described in detail. Suffice to say, however, that the combustion chamber 11 may be of the well known annular type or alternatively of the cannular type so that it is one of an annular array of similar individual combustion chambers or cans. In the case of a cannular combustion chamber, one fuel injection arrangement 60 would normally be provided for each combustion chamber 11. However, in the case of an annular combustion chamber 11, the single chamber would be provided with a plurality of fuel injection arrangement 60 arranged in an annular array at its upstream end. Moreover, more than one such annular array could be provided if so desired. For instance, there could be two coaxial arrays.

Figure 2 shows a prior art piloted airblast lean direct fuel injector arrangement 60, which is described in detail in US6,272,840, the teachings of which are incorporated herein by reference. However, the main features are briefly described where particularly relevant to the present invention. The injector arrangement 60 is generally annular and symmetrical about an injector axis 62 and is disposed at the upstream end of the combustion chamber 11.

The fuel injector arrangement 60 comprises a pilot or primary injector 12 and a pilot swirler 14 generally surrounding the pilot injector 12. A main airblast fuel or secondary injector 16 is concentrically positioned around

the pilot injector 12 and inner and outer main swirlers 18, 20 are concentrically disposed radially inwardly and outwardly respectively of the main airblast fuel injector 16.

An annular air splitter 22 is located between the pilot swirler 14 and the inner main swirler 18. The air splitter 22 comprises an air inlet 24 and downstream, an air outlet 26. The air splitter 22, in the direction of air flow, further comprises a generally cylindrical portion 28, a radially inwardly tapered portion 30 and a downstream portion 32 that is tapered still further radially inwardly.

In use, fuel flows through galleries 64 and 66 and exits through orifices 76, 78, which are defined by annular and co-axial members 68, 70 and 72, 74, of the main and pilot fuel injectors 16 and 12 respectively. The annular members 68 and 72 are fuel prefilmers having surfaces 80, 82 that the fuel flows over prior to being shed from downstream edges 44, 45 into the swirling airflows.

The geometry and position of the air splitter 22 is such that it separates the air flow exiting the pilot injector 12 and the main injector 16 thereby creating a bifurcated recirculation zone between the pilot and main air flows. The creation of the bifurcated recirculation zone, that aerodynamically separates the pilot flame from the main flame, benefits the lean blowout stability of the fuel injector arrangement 60. The pilot fuel stays nearer to the injector axis 62 and evaporates there, thus providing a richer burning zone for the pilot flame than is the case for the main flame. The fuel/air ratio for the pilot flame remains significantly richer than that for the main flame over a wide range of operating conditions. Most of the NOx formation occurs in this richer pilot flame, and minimizing the proportion of total fuel going to the pilot flame may further reduce NOx. The main injector supplies the majority of the combustion gases at most engine operating conditions, so that low levels of oxides of

nitrogen (NOx) emissions are obtained because the main injector produces a uniformly mixed fuel-air mixture at an equivalence ratio less than stoichiometric. This mixture burns at a relatively low flame temperature avoiding the NOx producing high temperature volumes of more conventional combustion systems.

Although combustion systems, such as the prior art device described above, can produce NOx emissions levels significantly lower than conventional combustion systems, they have severe disadvantages. One of these is combustion instability.

During testing of this prior art fuel injection arrangement 60, a high degree of combustion instability was experienced. This combustion instability is believed to occur due to insufficient mixing of the fuel and air mixture. Pressure fluctuations, arising from the combusting fuel vapour, travel upstream into the injection arrangement 60 where they cause the air velocity passing therethrough to pulsate. The air mass flow past the fuel injection planes therefore also varies. However, as the air pressure fluctuations are small relative to the fuel injection pressure there is no accompanying change in instantaneous fuel-flow. Instead of producing a temporally uniform air-fuel ratio, the injection arrangement 60 produces a uniformly spatially mixed air-fuel ratio, varying cyclically in time at the pressure fluctuation frequency. As heat-release from the combustion process is closely related to air-fuel ratio, temporal variations in air-fuel ratio within the premixer produce temporal variations in heat-release within the combustor chamber 11. These in turn generate the pressure fluctuations within the combustion chamber that cause the air-fuel ratio entering the combustion chamber 11 to oscillate on the next cycle. Thus a detrimental feedback loop is established.

Where variations in heat release and pressure are in phase, the magnitude of both fluctuations will increase.

The severity of the combustion instability produced varies from an irritating noise to a force powerful enough to stall gas turbine compressors and shake combustion systems apart. In a conventional aerospace gas turbine combustion system, different areas within the combustor operate at different air-fuel ratios. Here, fluctuations in heat release become out of phase relative to each other resulting in a reduction of the net heat-release. At certain engine operating conditions, the combustion system runs at a uniform air-fuel ratio, all parts of the combustion system tend to oscillate in phase with each other. Net heat release fluctuations therefore tend to be high.

It is an object of the present invention to provide a means for reducing combustion instability and in particular reducing net heat release fluctuations within the combustor. Therefore it is desirable to achieve improved mixing of the fuel/air mixture prior to its combustion.

To further enhance the mixing of the fuel film in the airflows the downstream edges 44, 45 comprise fluid flow mixing means 34 in accordance with a first embodiment of the present invention.

Figure 2a shows the fluid flow mixing means 34 as an array of lands 84 disposed around the inner circumference of the prefilmer 68 near to the downstream edge 44. The lands 84 enhance mixing the fuel and air by generating vortices, shown by the sequence of arrows 86, which breaks up the fuel into yet smaller particles. The smaller the particle size of the fuel, the greater the surface area of a given fuel quantity and therefore the quicker it is vaporised.

As shown in Figure 2a, the lands 84 are four sided and comprise a leading edge 88, two opposing sides 90, a leeward face 92 and a base attached to the prefilmer 68. Air flowing in the direction of arrow B flows over the edge between a side 90 and the leeward face 92 and in so doing a

vortex is imparted into the air flow as shown by arrows 86. The lands 84 are generally orientated parallel to the injector main axis 62.

It should be apparent to one skilled in the art that other shapes of lands 84 may be used but they do not depart from the scope or spirit of the present invention if they produce vortices which enhance the mixing of the air and fuel fluid flow. For example the size, positioning and number may be altered to suit each particular application. Furthermore, the orientation of the lands 84 may be altered so that for instance a land axis 36 is orientated in the general direction of the swirling air flow; the direction of the swirling airflow may not necessarily be aligned with the injector axis 62.

In an alternative embodiment of the injector 60, the fuel is discharged onto a radially outer surface 81 or 83 of the prefilmers of the main injector 16 or pilot injector 12. In this embodiment, the fluid flow mixing means 34 is disposed to the radially outer surfaces 81, 83 and operates in a similar fashion to the foregoing embodiment.

Figure 3 shows a second embodiment of a main injector 16 in accordance with the present invention, although this embodiment is equally applicable to the pilot injector 12. For brevity only the annular members 68, 70 are shown and like reference numerals are used for like elements throughout the description of the present invention. The annular members 68, 70, of the main injector 16, are generally annular having a downstream edge portion 44 which itself comprises a fluid flow mixing means 34. Each fluid flow mixing means 34 is designed to impart mixing vortices into the fluid flow thereby enhancing the mixing of fluid flowing therepassed and consequently improving the fuel/air mixture ingressing to the combustion chamber 11.

The main injector 16, in accordance with the present invention, continues to function in a conventional manner as described hereinbefore. In operation fuel flows through

the passageway between annular members 68, 70, through the orifice 76 and across the fluid flow surface 80. The fuel runs over the surface 80 and is shed from its downstream edge 44.

The purpose of introducing a fluid flow mixing means 34 is to further break up the liquid fuel into a smaller particle size. By doing so the surface area of a particular quantity of fuel is increased which intrinsically increases the rate that the fuel is vaporised.

The main injector 16 and indeed the pilot injector 12, is intended to be an alternative to the injectors 16 and 12 shown and described with reference to Figures 2 and 2a. The downstream edge 44 of the main injector 16 comprises an array of generally trapezoidal shaped projections 48, substantially aligned with and generally extending in the downstream direction of the injector axis 41, and which taper in the downstream direction. The projections 48 are equally spaced around the circumference of the main injector 16. Alternatively, the projections 48 may be spaced unequally around the circumference of the downstream edge 44.

Figure 4 shows a third embodiment of a main injector 16 in accordance with the present invention, again this embodiment is equally applicable to the pilot injector 12. For brevity only the annular members 68, 70 are shown and like reference numerals are used for like elements in Figure 2. The annular members 68, 70, of the main injector 16, are generally annular having a downstream edge portion 44 which itself comprises a fluid flow mixing means 34. Each fluid flow mixing means 34 is designed to impart mixing vortices into the fluid flow thereby enhancing the mixing of fluid flowing therepassed and consequently improving the fuel/air mixture ingressing to the combustion chamber 11.

The downstream edge 44 of the main injector 16 comprises an array of generally triangular shaped projections 52, the apex of each being downstream. Each projection 52 is equally spaced around the circumference of the main injector 16 and is radially inwardly angled. In the embodiment shown, the projections 52 are angled at approximately 45^0, relative to the axis 62, and are generally aligned with the taper angle of a radially outer surface 81 of the annular member 68. Although an angle of 45^0, is shown the invention may be practised if the projections are within the range $0-45^0$. However, it should be appreciated to the skilled artisan that angles up to 90^0, relative to the injector axis 62 would also provide the desired generation of air/fuel mixing vortices.

Referring to both Figures 3 and 4, the projections 48, 52 are formed by laser or electro-discharge cutting V-shaped or trapezoidal shaped notches 50, 54 from a main injector 16 initially having a planar downstream edge. Therefore the projections 48, 52 are curved along their circumferentially length. Although the projections are shown as straight (in the axial direction), they may also be curved either radially inwardly or outwardly in the axial direction. It should be appreciated that the size, angle and circumferential positioning of the projections are dependant on each particular application and a general design philosophy dictates that a compromise exists between the amount and strength of vortices generated and the degree of fluid stream energy losses encountered.

Although Figures 3 and 4 refer preferentially to trapezoidal and triangular shaped projections 48, 52 the skilled artisan may implement other shaped projections without departing from the scope and spirit of the present invention. Other suitable shapes for the projections comprise quadrilateral, polygonal or semi-circular or generally arcuate projections.

Furthermore, the projections 48 may be alternately angled radially inwardly and outwardly thereby imparting vortices within either the radially inward or outward fluid flows passing through the inner and outer main swirlers 18, 20.

Figure 5 shows a fourth embodiment of the present invention comprising the downstream edge 44 (or 45) arranged in a generally sinusoidal form in its axial direction, i.e. a peak 56 is downstream of a trough 58. The sinusoidal shaped downstream edge 44 directs portions of the fluid flows that pass radially inward or outward of the main injector 12, into one another thereby promoting mixing of the two fluid flows. The radial height difference between the peaks 56 and troughs 58 may be varied depending on each particular application, as may the number of peaks 56 and troughs 58 around the circumference of the downstream edge 44.

In an alternative arrangement of the downstream edge 44, the sinusoidal form is substantially in the radial direction so that the peaks 56 are radially outward of the troughs 58. This promotes forced mixing between radial inner and outer swirling airflows and therefore enhances the amount of mixing of the fuel and air fluid flow.

Furthermore, the downstream edge 44 may comprise a compound shape that is substantially sinusoidal in shape in both the axial and radial directions.

Although the embodiments of the present invention have been described with reference to the fluid flow mixing means 34 being disposed to the downstream edge 44, 45 of a prefilmer 26, over which fuel flows, the fluid flow mixing means 34 may also be disposed to any downstream edge of a fuel injector where only air flow over. This enhances the mixing capability of that air flow where it coalesces with a fluid flow comprising fuel liquid of vapour.

A further advantage of the present invention and particularly associated to Figures 3,4 and 5 is that at low

fuel flows the downstream edge of the prefilmers 68 create "streakiness" in the fuel flow flowing off the downstream edge. Low fuel flows are used at low engine power and at low power ignition. The streakiness of the fuel film coming off the downstream edge is relates to a variation in fuel film thickness associated with the shape of the downstream edge. For embodiments shown in Figures 3 and 4, where the fuel flow leaves the downstream edge near the apex of a notch 50, 54 there is a thicker fuel film than near the apex of the projections 48, 52. For the embodiment shown in Figure 5, where the fuel flow leaves the downstream edge near the "apex" of a trough 58 there is a thicker fuel film than near the "apex" of a peak 56. Where the fuel film is thicker the resulting downstream fuel/air mixture is richer so that at low fuel flows a more stable combustion flame is present.

The embodiment described with reference to Figure 2 and 2A, also imparts "streakiness" to the fuel film at low fuel flows. Here the fuel is channelled between the lands 84, locally increasing its film thickness.

The skilled artisan may easily appreciate other embodiments that vary the fuel film thickness around the circumference. For instance a circumferential array of shallow, radial channels may extend from the fuel gallery to the downstream edge.

It should also be understood to the skilled artisan that for greater fuel flows the distribution of fuel becomes more uniform around the circumference and the prefilmer 68 therefore provides a fluid flow mixing means to, in use, enhance the mixing of fuel and air.

Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore

referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.